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(54) Positive Displacement Compressors

(57) A gas-compressing plant has a power source e.g. an electric motor 50, driving a rotary compressor of e.g. the meshing-screw type, 10 through a gear train 53, which may include two parallel shafts connected respectively to the male and female rotors 51, 52 of the compressor. The shafts include clutches 58, 59 and are attached to gears 56, 57 meshing (in series) with a gear 55 fixed to the output shaft of the motor. Control means are provided for operating the clutches to selectively connect the motor to either the male rotor or the female rotor and the gear ratios are selected so that two operating conditions are thereby provided for the compressor, a full speed condition and a part speed condition. To reduce power consumption the control means is responsive to pressure signals from a sensor positioned in the output line of a receiver to which compressed gas from the compressor is delivered, Figure 2 (not shown). Alternatively, the compressor is of the reciprocating-piston kind.

FIG. 1.

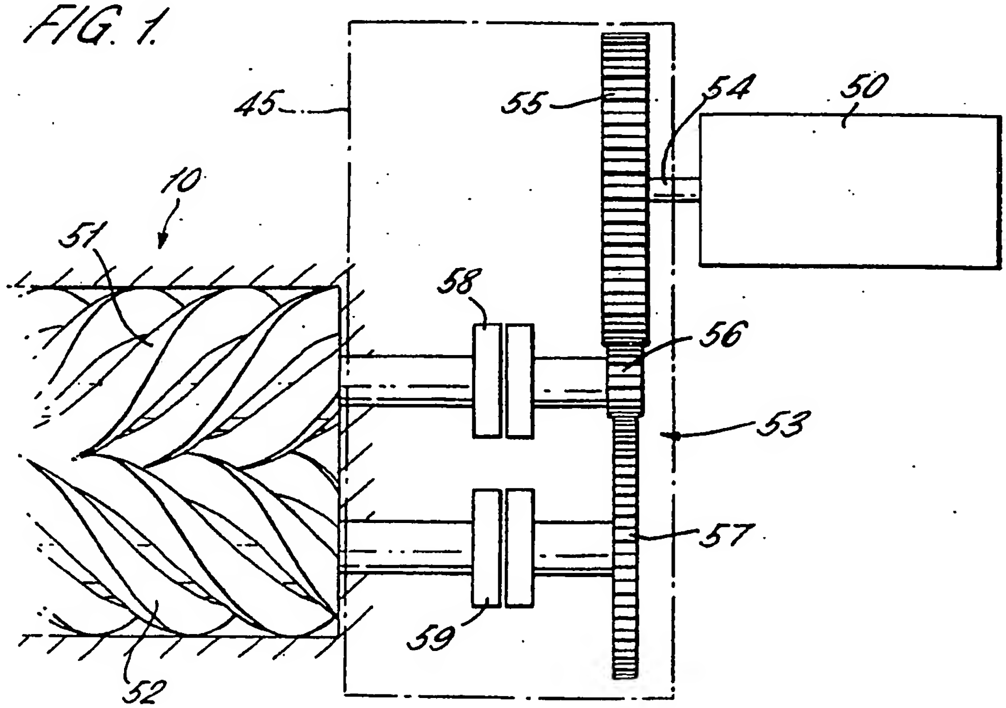

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FIG. 1.

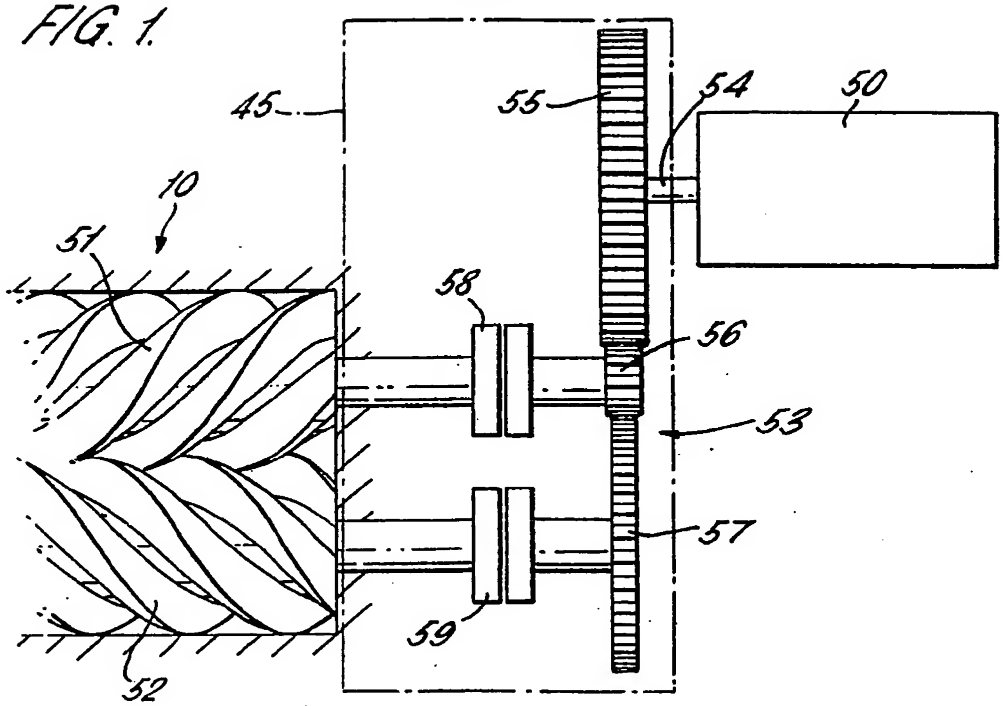
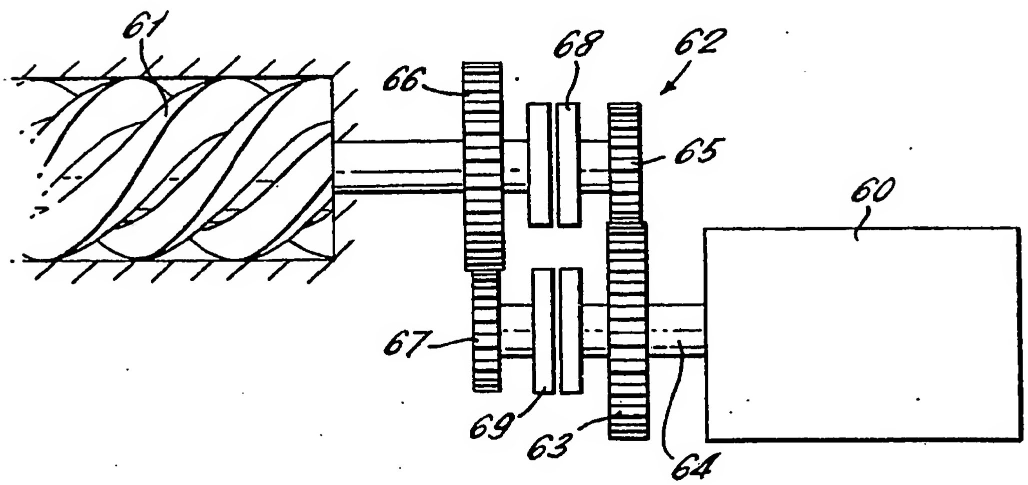


FIG. 4.



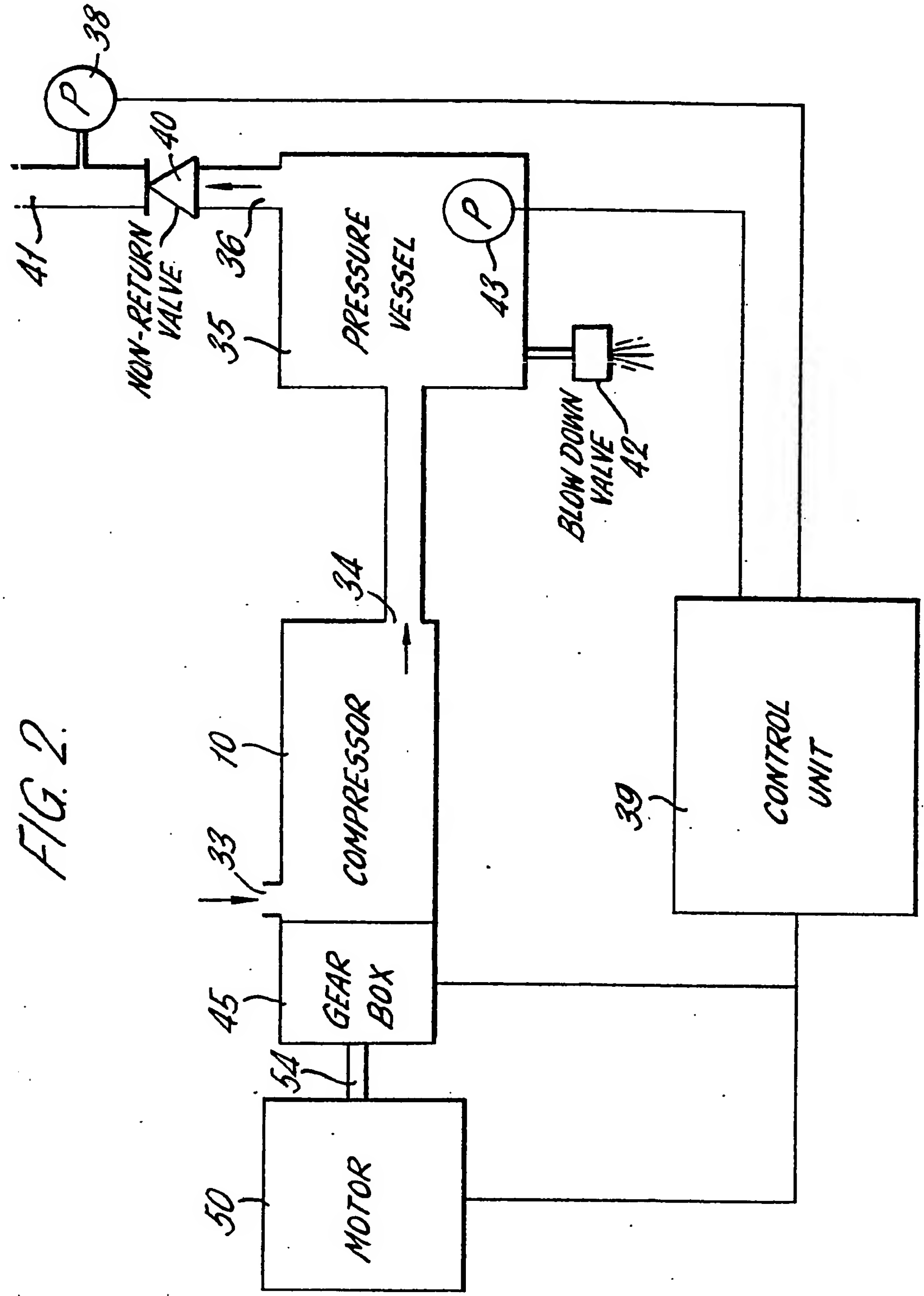
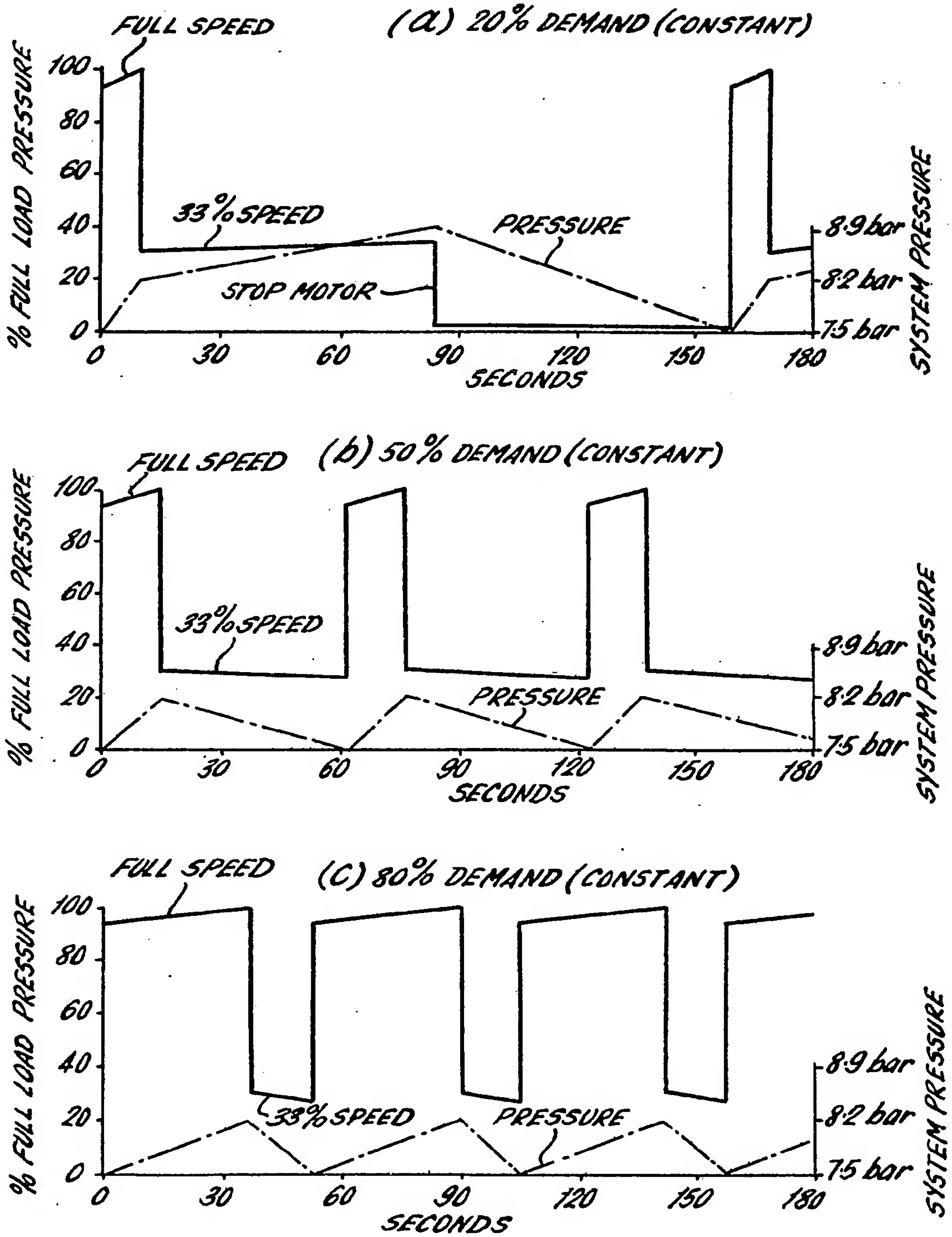

38
P
40
41
NON-RETURN VALVE
36
35
PRESSURE VESSEL
P
43
BLOW DOWN VALVE
42
34
COMPRESSOR
10
33
GEAR BOX
45
54
MOTOR
50
CONTROL UNIT
39

FIG. 2

FIG. 3.



(a) 20% DEMAND (CONSTANT)
FULL SPEED
33% SPEED
PRESSURE
STOP MOTOR
% FULL LOAD PRESSURE
100
80
60
40
20
0
0
30
60
90
120
150
180
SECONDS
8·9 bar
8·2 bar
7·5 bar
SYSTEM PRESSURE
(b) 50% DEMAND (CONSTANT)
FULL SPEED
33% SPEED
PRESSURE
% FULL LOAD PRESSURE
SECONDS
8·9 bar
8·2 bar
7·5 bar
SYSTEM PRESSURE
(C) 80% DEMAND (CONSTANT)
FULL SPEED
33% SPEED
PRESSURE
% FULL LOAD PRESSURE
SECONDS
8·9 bar
8·2 bar
7·5 bar
SYSTEM PRESSURE

SPECIFICATION

Improvements in Positive Displacement Compressors

The invention relates to positive displacement compressors and is particularly though not exclusively concerned with screw compressors.

It is clearly established that the ability to reduce the part load power consumption of compressor plants, particularly screw compressor plants, is of major advantage. A number of systems have been proposed for this purpose, including a suction regulator for continuous modulation flow control, a full slide-valve arrangement and a system for infinitely variable speed control. However, each of these systems has disadvantages and the present invention seeks to overcome these disadvantages. In particular, the present invention seeks to provide a system with a high level of efficiency over the whole range of system demand and particularly between 30% and 100% of maximum demand and to achieve this with a lesser number of components (and therefore at less cost) than has hitherto been the case.

The invention provides a positive displacement compressor comprising at least one compressing element rotatable or reciprocable in a housing having an inlet for fluid to be compressed and an outlet for compressed fluid, a power source, a gear train for connecting the power source to the compressing element to drive the element, said gear train including means for connecting the power source to the compressing element for driving the element in two discrete speed conditions, a full speed condition and a part speed condition, and control means for operating the gear train to switch the compressing element from one speed condition to the other in response to pressure signals from the output side of the compressor.

Preferably the compressor is a screw compressor in which the compressing element is a male rotor which meshes with a female rotor.

Preferably the gear train includes a first shaft connected to the male rotor for driving said rotor and a second shaft connected to the female rotor for driving the male rotor through the female rotor, the connecting means being operable to connect the power source to either the first shaft or the second shaft.

The connecting means may comprise a first clutch for the first shaft and a second clutch for the second shaft.

The gear train may include a plurality of meshing parallel-shaft gears, a first gear fixed on an output shaft of the power source, a second gear connected to the first clutch and a third gear connected to the second clutch.

The power source is preferably an electric motor, and the control means is preferably operable also to switch the motor on and off.

In a second embodiment, the gear train includes an output shaft connected to the male rotor, at least two meshing parallel-shaft gears and clutch means for connecting each of the gears to the output shaft.

The compressor described above is preferably part of a plant further comprising a receiver for compressed gas, means connecting the compressor outlet to the receiver, an outlet from the receiver and a non-return valve in the receiver outlet, the pressure signals for the control means being provided by a pressure sensor in the receiver outlet downstream of the non-return valve.

Further features and advantages of the invention will become apparent from the following description, by way of example, of some preferred embodiments of a positive displacement compressor according to the invention, the description being read with reference to the accompanying drawings, in which:—

Figure 1 is a schematic side view of a first embodiment of a screw compressor according to the invention;

Figure 2 is a block diagram of compressor plant including the compressor of Figure 1;

Figure 3 shows sketches of tha operating cycle of the plant of Figure 2; and

Figure 4 is a view similar to Figure 1 of a second embodiment of a screw compressor.

Referring first to Figure 1, a screw compressor 10 has a male rotor 51 in mesh with a female rotor 52.

A prime mover 50 (for example, a four-pole electric motor) is selectively connectible to either the male rotor 51 or the female rotor 52 of the screw compressor via a parallel shaft gear train 53 housed in a gear casing 45. The gear train 53 comprises an input gear 55 fixed to the output shaft 54 of the prime mover, and two gears 56, 57 driven by the input gear 55. Gears 56, 57 are connectible to respective rotors, 51 52 through clutches 58, 59 respectively.

The diameters of gears 55, 56, 57 are selected for desired operating speeds. For example, in the usual case where the male rotor has four lobes and the female rotor has six lobes the female rotor speed is two-thirds of the male rotor speed. Thus if it is desired that the male rotor speed when driven through the female rotor should be approximately one third of full speed (when drive is through the male rotor) and gears 55, 56 are in mesh, the ratio of gears 56, 57 is $1:4\frac{1}{2}$.

In use of the compressor shown in Figure 1, when it is desired to drive the compressor at full speed, clutch 58 is engaged and clutch 59 is disengaged so that the prime mover drives the male rotor 51 at a speed determined by the ratio of gears 55 and 56. When it is desired to run the compressor in its lower speed mode, the clutch 58 is disengaged and clutch 59 is engaged so that the prime mover now drives the female rotor and the male rotor rotates at one third of the full speed.

Turning now to Figure 2, screw compressor plant including the compressor 10 is illustrated. As described above, the compressor is driven via the gear train 53 by an electric motor 50. Air

enters the compressor through inlet 33, is compressed by the rotors 51, 52 and is forced out through outlet 34. The compressed air from the outlet passes to a pressure vessel 35 including an outlet 36 and thence via a non-return valve 40 to a pipe 41 for delivery of compressed air to a user system. The pressure vessel 35 includes a blow down valve 42.

Mounted within the pipe 41 is a pressure sensor 38 which is connected to a control unit 39 for actuating the motor and the two clutches within gear casing 45. The control of the motor and clutches permits various operating modes of the compressor as follows.

1. With the motor 50 running the clutch 58 engaged and the clutch 59 disengaged so that drive is to the male rotor, full speed of the rotors is obtained, this speed being the gear ratio of the gears 55, 56 times the motor speed. In a typical arrangement, the 4-pole electric motor has a speed of 1500 r.p.m. and the gear ratio of gears 55, 56 is approximately 3:1 giving a rotor speed of approximately 4500 r.p.m.

2. With the motor running, the clutch 58 disengaged and the clutch 59 engaged to provide drive to the female rotor, the male rotor speed falls to approximately one-third of its full speed as described above.

In the example given, this one-third speed is approximately 1500 r.p.m. In this condition, the rotors are driven at approximately one third of full speed so that approximately one third of the maximum compressor output is produced from one third of the nominal input power.

3. With the motor stopped and both clutches released, the rotor speed will fall to zero.

The control unit 39 switches the compressor between these three operating conditions in response to pressure signals from the sensor 38 as follows.

If the system demand for compressed air from pipe 41 is high, the compressor will be in condition *1*. If the demand is less than 100% of compressor capacity, this full speed running of the compressor will cause the pressure in the user's system and hence in pipe 41 to build up. When the pressure reaches a first predetermined value (in one example, 8.2 bar), the control unit disengages clutch 58 and engages clutch 59 so that the compressor runs in condition *2*, producing about one-third of full output.

If the system demand at this time is greater than the compressor output the pressure will drop to a third predetermined value (in the example, 7.5 bar) when the clutch 58 will be re-engaged (and clutch 59 disengaged) with the result that the 100% compressor speed condition, will be re-established.

If, on the other hand, the system demand for compressed air is less than that provided by the compressor running in condition *2*, the pressure in the user's system will continue to rise. When this pressure reaches a second predetermined value (in the example, 8.9 bar) the control unit switches off the motor to put the compressor in condition *3*. The system pressure then gradually falls.

While the compressor is stopped (in condition *3*), the pressure in the pressure vessel will fall to zero by action of the blow down valve 42, the non-return valve 40 being shut. The blow down valve is automatically opened when the motor electrical supply is switched off.

When the system pressure falls to the third predetermined value (7.5 bar), the control unit restarts the motor with clutch 59 still engaged so that the compressor restarts at one-third speed (in condition *2*), and against zero pressure on the pressure vessel 35. An overriding signal of pressure in the receiver 35 (sensed by a second pressure sensor 43 in the receiver) keeps clutch 58 disengaged until the pressure in the receiver exceeds the pressure in the pipe 41 at which time clutch 58 is re-engaged and the compressor continues at full speed.

As the motor builds up speed, the pressure in the pressure vessel rises (the blow down valve 42 being now shut) until the pressure reaches the same value as exists in the user's system. The non-return valve then opens allowing air into the user's system and pressure again rises.

Figure 3 illustrates examples of typical regulation cycles of the compressor plant. In these examples the predetermined pressures are as quoted above and the system demand is assumed to be constant. Figure 3(a) shows the regulation cycle with a constant demand of 20% of maximum, Figure 3(b) the cycle for 50% demand and Figure 3(c) the cycle for 80% demand. In each of these Figures, the receiver pressure is also shown in chain-dot lines. It will be observed that at 50% and 80% demand, the motor is running constantly and the compressor switches between conditions *1* and *2* only.

Although the described embodiment is a screw compressor, it will be appreciated that the drive arrangement described is equally applicable to other sorts of positive displacement compressors, for example reciprocating piston compressors.

It will also be appreciated that the selected part speed condition need not be one third of full speed (of the male rotor) and various other part-speeds may be obtained simply by varying the ratio of gears 56, 57. Furthermore, both the full and part-speeds may be altered simply by changing gear 55.

An advantage of providing the drive gear 55 in mesh with gear 56 rather than gear 57 is that less power is transmitted through gear 57 and so the face width of that gear may be reduced.

Figure 4 illustrates a further embodiment of a drive arrangement for a screw compressor which also provide two distinct speeds of rotation of the compressor rotors.

In Figure 4, a prime mover 60 is connectible to the male rotor 61 of a screw compressor via a parallel shaft gear train 62. The gear train 62 comprises a first gear 63 fixed to the output shaft 64 of the prime mover 60 and in mesh with a second smaller gear 65. A third gear 66 of the same size as the first gear 63 is fixed to the shaft

of the rotor 61 and is in mesh with a fourth gear 67 of the same size as the second gear 65. The second gear 65 is connectible to the third gear 66 by a clutch 68 and the first gear 63 is connectible to the fourth gear 67 by a clutch 69. When it is desired to drive the rotor 61 at full speed, the clutch 68 is engaged with clutch 69 disengaged. The rotor speed is then the ratio of first gear 63 to second gear 65 times the prime mover output speed. For example if the gear ratio is 2:1 and the prime mover is a 2-pole electric motor running at 3000 r.p.m. the rotor speed will be about 6000 r.p.m. When it is desired to drive the rotor in its low speed condition, clutch 68 is disengaged and clutch 69 engaged. The motor speed will now be the ratio of fourth gear 67 to third gear 66 times the prime mover output speed. For example, if the gear ratio is 1:2 then the male rotor speed will be 1500 r.p.m.

Although the first and third gears and second and fourth gear respectively are described as being of the same size, it will be appreciated that the important constraint is that the centre distances of the two pairs of gears (first and second, third and fourth) are equal and any desired gear ratios may be adopted that satisfy this condition.

Thus, it can be seen that the arrangement of Figure 4 provides a full-speed and a part-speed operating condition of the compressor in the same way as the arrangement of Figure 1 and operating cycles similar to those shown in Figure 3 may be achieved by appropriate control of the clutches of Figure 4.

The invention is not limited to the preferred embodiments described above and various modifications may be made. For example, in the Figure 1 embodiment the gear 55 may mesh with gear 57 rather than gear 56 in which case the ratios of gears 55:57:56 will be 2:1:2.

Futher, although all the clutches 58, 59, 68, 69 are illustrated as plate clutches, any or all of them may be "one-way" clutches.

Claims

1. A positive displacement compressor comprising at least one compressing element rotatable or reciprocable in a housing having an inlet for fluid to be compressed and an outlet for compressed fluid, a power source, a gear train for connecting the power source to the compressing element to drive the element, said gear train including means for connecting the power source to the compressing element for driving the element in two discrete speed conditions, a full speed condition and a part speed condition, and control means for operating the gear train to switch the compressing element from one speed condition to the other in response to pressure signals from the output side of the compressor.

2. A compressor as claimed in claim 1 being a screw compressor in which the compressing element is a male rotor which meshes with a female rotor.

3. A compressor as claimed in claim 2 in which the gear train includes a first shaft connected to the male rotor for driving said rotor and a second shaft connected to the female rotor for driving the male rotor through the female rotor, the connecting means being operable to connect the power source to either the first shaft or the second shaft.

4. A compressor as claimed in claim 3 in which the connecting means comprises a first clutch for the first shaft and a second clutch for the second shaft.

5. A compressor as claimed in claim 4 in which the gear train includes a plurality of meshing parallel-shaft gears, a first gear fixed on an output shaft of the power source, a second gear connected to the first clutch and a third gear connected to the second clutch.

6. A compressor as claimed in any one of the preceding claims in which the power source is an electric motor.

7. A compressor as claimed in any one of the preceding claims in which the control means is operable also to switch the power source on and off.

8. A compressor as claimed in claim 2 in which the gear train includes an output shaft connected to the male rotor at least two meshing parallel-shaft gears and clutch means for connecting each of the gears to the output shaft.

9. A compressor plant comprising a compressor as claimed in any one of the preceding claims, a receiver for compressed gas, means connecting the compressor outlet to the receiver, an outlet from the receiver and a non-return valve in the receiver outlet, the pressure signals for the control means being provided by a pressure sensor in the receiver outlet downstream of the non-return valve.

10. A positive displacement compressor substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

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